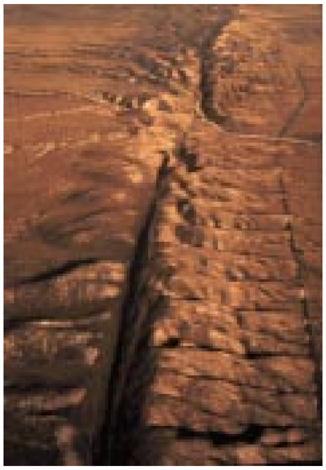
What Is the Nature of Deformation at Plate Boundaries and What Are the Implications for Earthquake Hazards?



The San Andreas fault cuts through 1,200 km of California and is one of the most active fault systems in the world.

Expected Accomplishments

- *Characterization of motions of the Earth's surface and their variability on a global scale*
- *Understanding of fault interactions and transfer of stress through the crust*
- *Models that predict the behavior of earthquake systems*

Benefits for the Nation

- *Enabling of rapid response to seismic disasters worldwide*
- *Enhanced global maps of natural hazards to support mitigation strategies*
- *Determination of the existence of local and regional precursors to earthquakes*

The Challenge

Earthquakes are among nature's most complex phenomena, threatening many of the world's population centers. A great Pacific Rim earthquake near a major economic area might cause damages well in excess of one trillion dollars and tens of thousands of casualties. Reaching an understanding of earthquake fault systems is required in order to address the issue of their predictability, with the goal of mitigating their impact.

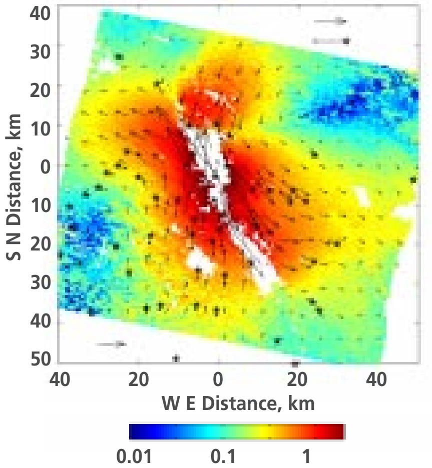
"The laws of nature are written deep in the folds and faults of the earth."

John Joseph Lynch, former president of the New York Academy of Sciences, 1963

Key questions include:

- How do individual faults behave and interact as part of an integrated system?
- What are the mechanical properties of the crust and mantle that control deformation?
- To what extent can earthquakes be forecast?

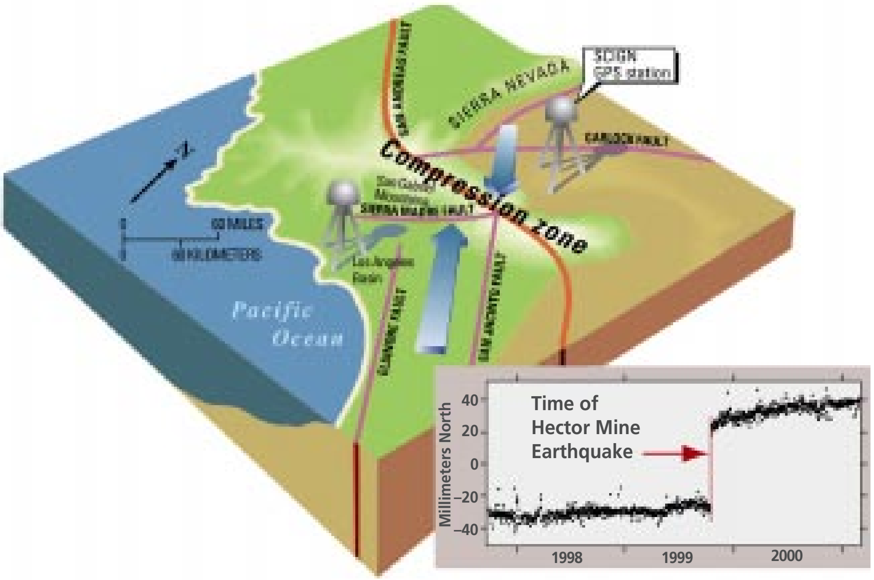
Investigations of surface deformation, plate-boundary motion, frictional properties of faults, and mechanical properties of the Earth's crust are necessary to determine what controls the spatial and temporal patterns of earthquakes. Space-based observations allow us to follow the entire earthquake cycle, including the aseismic accumulation of strain. These new measurements are providing insights into how stress is transferred between



Displacement from the 1999 magnitude 7.1 Hector Mine earthquake in California as measured using InSAR techniques. The radar echoes are reduced to interferograms by calculating the phase differences between images from multiple satellite passes. Color (using a logarithmic scale) represents horizontal displacement in units of meters. Arrows show both magnitude and direction.

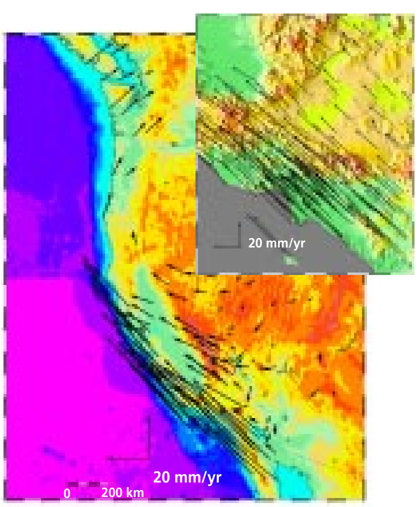
faults, how much energy is released by earthquakes versus other modes of deformation, and how faults fail.

Fully modeling the earthquake system requires knowledge of both current and past motions and fault interactions. It is necessary to measure the ongoing deformation associated with plate tectonics and motion along faults. It is also necessary to obtain detailed topographic and geomorphic characteristics of faults in order to better understand earthquake history. Targeted measurements along plate-boundary zones can address how fault systems interact. Because we are discovering that such interactions may extend to hundreds of kilometers distance, explor-



Geodetic data from ~250 GPS stations primarily within the SCIGN array in Southern California provide a powerful tool for studying surface deformation and earthquakes, such as the slow strain buildup along the San Andreas and other faults. The inset shows the change in the north–south position of a SCIGN station near Palm Springs before and after the Hector Mine earthquake (about 50 miles from the epicenter).

atory large-scale measurements are also required until we understand these systems better. For example, by understanding the stress changes that occur after major earthquakes, it may be possible to determine more reliably the probability of future earthquakes occurring at other locations



The surface velocity field of western North America, and the Los Angeles basin (inset), as observed by GPS.

in the system. Analyses of the transient changes and spatial complexity of deformation are likely to reveal previously unrecognized properties of the faults and of the Earth's crust. A complete program of study will integrate global-scale measurements and large-scale computing with laboratory and in situ measurements sponsored by other agencies to treat in an integrated fashion all aspects of the earthquake physics problem.

What We Know and Need to Learn about Deformation at Plate Boundaries and Earthquakes

Our knowledge of Earth surface deformation is discontinuous in both time and space. At global scales, plates move steadily relative to each other over long periods. Plate-boundary zones are typically broad on continents and narrow in oceanic regions. Plate boundary zones can be made up of many faults separated by either rigid or deforming blocks. Elastic strain accumulates in a broad zone across a fault and is released suddenly during an earthquake. The crust continues to respond following earthquakes. Faults can continue to slip for years, and deformation propagates in the crustal layer and upper mantle as stresses are redistributed over decades or even centuries. Recent evidence indicates that faults interact, and earthquakes can influence faults up to several hundred kilometers away. This influence is probably determined by the structure and composition of crustal layers and frictional properties of faults and can best be understood by observing and simulating the motions of the Earth's surface throughout several seismic cycles.

Next Steps

To achieve a better understanding of the nature of deformation at plate boundaries requires information on the changes occurring at the Earth's surface, including the seafloor, and within the interior. Varying temporal and spatial sampling requirements and accuracies dictate specific observational approaches: GPS networks, InSAR constellations, and spaceborne laser altimetry and lidar will be needed to provide dense spatial and temporal sampling and high-accuracy observations of the changes on the Earth's surface. These data will complement information obtained from seismic networks, seafloor geodesy, borehole arrays, and highly accurate gravity measurements. The ensemble of data combined with advanced geophysical modeling will allow quantitative prediction of many aspects of fault zone deformation.